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Recovery of Gold from Gold Plating Industry Wastewater Using an Agricultural Waste: Hard Shell of Apricot Stones

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Abstract

Activated carbons are extremely versatile adsorbents for major industrial significance, especially for metal ions recovery from wastewaters. In this study, the activated carbon prepared from the hard shell of apricot stones, an agricultural solid, which was used for the gold recovery from gold-plating wastewater is investigated. Activated carbon was produced by chemical activation with phosphoric acid. Recovery parameters such as adsorbent dose, the particle size of the activated adsorbent, pH and the agitation speed of mixing were studied. The equilibrium data fit well with the Freundlich isotherm model. A Langmuir isotherm model has been used to obtain thermodynamic parameters. The results showed that under the optimum operating conditions, more than 98 per cent of the gold was recovered by activated carbon after only 3 hours. It was found that the activated hard shell of apricot stones could be used as an effective adsorbent for gold recovery from wastewaters.

Keywords*: Gold Recovery, Plating Wastewater, Agricultural Waste, Hard Shell of Apricot Stones*

1- Introduction

Activated carbon is a generic term for a family of highly porous carbonaceous materials which can be characterized by a structural formula or by chemical analysis [1-5]. Activated carbon can be produced from virtually any carbonaceous solid precursor by a physical or chemical activation process [4-8]. Common examples of commercial feedstocks are coal, wood and agricultural residues such as coconut shell, fruit stones (apricot and cherry stones, grape seeds), hard shells (almond, pistachio and pecan shell), sugar cane bagasse, etc [4, 5, 8-14].

Important applications of activated carbons are related to their use in water and industrial wastewater treatment for the removal of flavor, color, odor and other undesirable organic impurities [2,4,12]. Activated carbon has found increasing application in the field of hydrometallurgy, especially in gold and silver recovery from cyanide solutions [3,15].

As a result of practical and theoretical advancements in recent years, the carbon-in-pulp (CIP) process has become the preferred method for gold recovery from aurocyanide slurries or dilute solutions. In the CIP process, the dissolved gold is adsorbed on

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activated carbon directly from the cyanide pulp [3, 16-19].

The main advantages of activated carbon are: its high selectivity towards gold relative to base metals, its ease of elution and its large particle size [16,20]. It should be noted that the physical and chemical properties of the activated carbon used can strongly affect the gold recovery. The primary properties of activated carbon intended for use in a gold recovery process are as follows [15, 16, 21]:

1- high adsorption capacity (loading capacity)
2- high adsorption rate
3- good resistance to abrasion.

Coconut shells are the most widely used raw material for the production of activated carbon suitable for CIP plants. However, increasing gold-production is likely to necessitate the exploitation of other sources. Abundance, ready availability and inexpensive agricultural by-products such as hazelnut shell, fruit stones, bagasse and rice husk make them a viable candidate for an alternative source of activated carbon [13,16, 21-23].

In Iran, most of the activated carbons used by industries are imported from countries like China, Sri Lanka and the Netherlands at a high expense. There is an opportunity to reduce the cost of these processes by producing activated carbon in Iran using domestic raw material resources [24, 25]. Residues from agriculture and food industries are the non-products outputs being produced from the growing and processing of raw agriculture such as the hard shell of nuts, bagasse and olive waste. In Iran, such low – value biomass are used inefficiently as fuel or discharged as waste [10, 26-29].

There are many studies in the literature relating to the production and characterization of activated carbon from agricultural waste [5,7-13]; however only a few publications concerning the preparation of an effective adsorbent from the hard shell of apricot stones can be found. The hard shell of apricot stones was selected because of their availability and desirable physical characteristics as activated carbon precursors (Iran produces about 280,000 tons of apricots each year, and it was estimated that 10 percent of apricot is its stone). Therefore, this research was carried out to investigate the potential of activated carbon from this waste as an effective adsorbent for the gold recovery from industrial wastewater.

2- Experimental

2-1- Activated carbon preparation

The required activated carbon was prepared from the hard shell of Iranian apricot stones by the chemical activation process as follows [24, 25, 30, 31]:

1- Hard shell of apricot stones were ground using a laboratory mill and sieved to obtain desired size fractions using a conventional sieve-shaker
2- The selected fraction of particle size (12<mesh<16) was dried at 100°C for 24 hours
3- Samples were impregnated with phosphoric acid solution in 1:1 wt. ratio
4- Mixture was kept in an oven at 100°C for 24 hours
5- Mixture was subjected to carbonization and an activation process in programmable electrical furnace (Nabertherm Labothem) with heating rate 5°C/min to a final carbonization temperature of 400°C.
6- The chemically activated carbon was washed extensively with hot distilled water until the pH of the wash water became neutral.
7- The washed activated carbon (HSAS carbon) was dried overnight at 100°C in an air oven.

The yield of this process and the percent of H_3PO_4 recovery were determined from the following equations, in which the parameters together give a measure of process efficiency:

$$\text{Process Yield} = \frac{activated\ carbon\ weight}{raw\ material\ weight}.100 \quad (1)$$

$$\text{Recovery} = \frac{\text{product weight before washing- product weight after washing}}{H_3PO_4 \text{weight for impregnation}}.100 \quad (2)$$

2-2- Activated carbon characterization

The characterization of activated carbon is important to their applications in the adsorption and separation process. Activated carbons were characterized by selected physical and chemical properties. These properties are generally used for characterizing commercial activated carbons.

2-2-1- Elemental Analysis

The analysis of the main elements of carbon samples (i.e. carbon, nitrogen and hydrogen) was performed by using a CHNS-O (Perkin Elmer series 2400II) elemental micro analyzer.

2-2-2- Surface area measurement

The surface area (S_{BET}) of activated carbons was determined from an adsorption-desorption isotherm of N_2 at 77 K. A Quantachrom NOVA 1000 surface area analyzer was used for this parameter by applying the 5-point BET (Brunaeur- Emmet –Teller). Before measuring the isotherm, the samples were heated at 473 K for 2 h in a vacuum for degassing. The pore volumes were calculated by the BJH method [32] .

2-2-3- Iodine number

The iodine number of prepared activated carbon was measured by titration at 30°C based on the standard method (ASTM Designation D4607-860). This parameter was used to evaluate the activated carbon adsorption capacity [33].

2-2-4- Bulk density

Apparent or bulk density is a measure of the weight of material that can be contained in a given volume under specified conditions. The volume used in this determination includes, in addition to the volume of the skeletal solid, the volume of the voids among the particles and the volume of the pores within the particles.

A 10 ml cylinder was filled to a specified volume with activated carbon that had been dried in an oven at 80°C for 24 h. The cylinder was weighed and the bulk density was then calculated as [34]:

Bulk density = [weight of dry material (g)/vol. of packed dry material (ml)] (3)

The volume of this vessel was calibrated by measuring the volume of water at the ambient temperature that the vessel can contain.

2-2-5- Attrition

Activated carbon hardness was determined using a wet attrition test as described by Toles, et al. [35]. Tenthirty mesh carbons were used. One gram of activated carbon was added to 100 ml of acetate buffer in a 150 ml beaker. The solution was stirred for 24 h at 25°C on an IKA magnetic stirrer at 500 rpm using 0.5" stir bars. The samples were then poured onto a 50 mesh screen and the retained carbon was washed with 250 ml deionized water. After washing, the retained carbon was dried at 110°C for 2 h. The sample was removed and allowed to cool in a desiccator and weighed. The percent of attrition was calculated as:

$$\% \, Attrition = \frac{initial \; Nt(g) - \; final \; Nt(g)}{initial \; Nt(g)}.100 \quad (4)$$

2-2-6- Ash content

The ash content (Ash %) of an activated carbon is the residue that remains when the carbonaceous portion is burned off. The ash content of activated carbon was determined by standard methods [36].

2-2-7- Conductivity

Conductivity is a measure of water-leachable minerals and a function of how extensively the carbons were washed before use. Conductivity measurements were carried out using Ahmedna's method. A 1% (wt./wt.) solution of activated carbon in deionized water was stirred at room temperature for 20 minutes. Electrical conductivity was measured using an EDT instrument BA380 Conductivity meter with values given in micro siemens (μS) [37,38].

2-3- Gold Recovery Tests

2-3-1- Kinetic studies

The batch recovery experiments were performed on an orbital shaker (FINEPCR). In adsorption tests, wastewater from gold-plating industrial units was used as feedstock and the effects of parameters such as the dose and particle size of the adsorbent, pH and agitation speed of the solution were investigated. The process parameters and their levels are shown in Table 1.

In these experiments a measured volume of gold solution (50 ml) was contacted with a given weight of activated carbon in glass bottles. Samples were shaken at room temperature for 6 hours. In all tests the pH of the solutions was kept constant by adding small amounts of KOH solution (1N) or HCl (1N).

During the recovery tests, samples of the slurry were taken at regular time intervals. The carbon was separated from the sample by filtering, and the gold concentration of the solution was measured by an atomic absorption spectrophotometer (Unicam, model 939) with an air-acetylene flame and an absorbance peak at a wavelength of 242.8nm. The quantity of gold recovered by the activated carbon was determined from the difference of gold concentrations in the initial and final solution.

2-3-2- Equilibrium studies

Batch recovery studies were performed at different temperatures (25°C, 40°C and 60°C) to obtain the equilibrium isotherms and the data required for the treatment of gold bearing wastewater. For isotherm studies, a series of 100 ml glass vessels were employed. Each vessel was filled with 50 ml of gold solution of varying concentrations (20–150 mg/l) and adjusted to the pH 10.5. Approximately 1 gram of dry adsorbent was added into each vessel. The solution was gently mixed and equilibrated for 24 h. After this period the solution was filtered on a Whatman No. 42 filter paper and analyzed for the the gold concentration by AAS.

The gold concentration retained in the adsorbent phase (mg/g) was calculated by using

$$q_e = \frac{(C_0 - C_e)\,V}{W} \quad (5)$$

where C_0 and Ce are the initial and equilibrium concentrations (mg/l) of gold ion in the solution, V is the volume (l) and W is the weight (g) of the adsorbent.

2-4- Taguchi Method

The Taguchi method is a systematic application of design and analysis of experiments for the purpose of designing and improving product quality. In recent years, the Taguchi method has become a powerful tool for improving productivity during research and development so that high quality products can be produced quickly and at low cost.

Optimization of process parameters is the key step in the Taguchi method in achieving

a high quality without increasing the cost. This is because the optimization of process parameters can improve performance characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Usually, there are three categories of performance characteristic in the analysis of the S/N ratio, i.e. the lower-the better, the higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis [39,40].

Gold recovery tests were designed with the Taguchi method and the effectiveness of the parameters as well as the optimum operating condition was determined. In the present study, there are eight degrees of freedom owning to the four sets of three-level recovery process parameters. The degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters.

According to the Taguchi method, an L9 orthogonal array with four columns and nine rows is suitable for these experiments. The recovery parameters and their level are shown in Table 1. The experimental layout for these parameters using the L9 orthogonal array is listed in Table 2. The final gold recovery was measured after 6 hours. Final gold recovery is the higher-the-better performance characteristic.

Table 1. Gold Recovery parameters and their levels

Parameters	Unit	Level 1	Level 2	Level 3
Adsorbent Size	Mesh (mm)	35-16 (0.5-1.2)	16-12 (1.2-1.7)	50-35 (0.3-0.5)
Adsorbent Dose	g/l	1	2	20
Agitation speed	rpm	150	300	600
pH		9.0	10.5	12.0

Table 2. Arrangement of factors in L9 orthogonal array

Parameters / Experiment	Adsorbent Size (mm)	Adsorbent Dose (gl^{-1})	Agitation speed (rpm)	pH
t1	35-16	1	150	9.0
t2	35-16	2	300	10.5
t3	35-16	20	600	12.0
t4	16-12	1	300	12.0
t5	16-12	2	600	9.0
t6	16-12	20	150	10.5
t7	50-35	1	600	10.5
t8	50-35	2	150	12.0
t9	50-35	20	300	9.0

3- Results and Discussion

The results of this study are presented in four parts as follows:

1. The chemical and physical characteriza-tion of activated carbons
2. Gold recovery tests
3. Gold adsorption isotherms
4. Comparison of gold recovery with different activated carbons

3-1- Characterization of activated carbons

HSAS carbon is produced with production efficiency of about 45 per cent and chemical recovery about 90 per cent. Since the commercial application of activated carbons is affected by their physical and chemical properties, a comparison of these properties of HSAS carbon with three types of commercial samples is shown in Table 3. These imported commercial activated carbons are:

- C2: activated carbon used in the gold recovery process in Iran
- C3: activated carbon used in the gas phase separation process
- C4: activated carbon from the CECA company

Table 3. Physical and chemical properties of Activated carbons

Elemental analysis (%)			Suface area (m^2/g)	Volume of pores (ml/g)	Iodine number (mg I_2/g)	Bulk density (kg/m^3)	Attrition (%)	Ash (%)	Conductivity (μS)
C	H	N							
HSAS									
78.81	2.42	0.23	1387	0.954	669	451.5	3.40	0.2	295
C2									
92.10	0.54	0.18	1078	0.804	590	487.6	1.80	2.0	245
C3									
87.29	0.62	0.35	900	0.363	617	477.0	13.38	7.8	56
C4									
87.22	0.49	0.37	1050	0.892	836	500.0	0.78	6.8	50

According to Table 3, the surface areas of these carbons varied from 900 to 1387m^2/g with HSAS carbon having the highest surface area. While surface area is the most important property, pore size and surface chemistry also affect the adsorption of specific compounds.

Of the carbons analyzed, HSAS carbon has the lowest bulk density. Bulk density is important for activated carbon when the carbons are used in the column mode. When using the wet attrition test, the C4 carbon (provided by CECA) has less attrition (<1) than the other samples. However the HSAS carbon has a relatively good strength.

Ash in an activated carbon is an impurity and is not desired. It is important to note the lower ash content of HSAS carbon. This is most likely because of the low ash content of the apricot stones hard shell.

According to previous studies, a graphitic structure is essential for a carbon material to be an adsorbent for gold ions. Typically for any carbon products, the absence of a major mole fraction of sp^3 bound elemental carbon (indicated by high electrical conductivity) and polycyclic aromatic hydrocarbons (indicated by low hydrogen content) means that the elemental carbon must be in graphitic structure [41]. In the samples

analyzed, HSAS and C2 carbons have more conductivity than the other samples, and the C3 sample has the lowest H content (0.5 per cent). Results indicated that these samples have the graphitic structure.

3-2- Gold Recovery

The results of recovery experiments are shown in Fig. 1. As can be seen for all experiments, the gold recovery rate increases with time and reaches a maximum after 1.5 hours of contact time.

In these experiments, the percent of final gold recovery is selected as a response of the system in the Taguchi method, and optimum operating conditions are determined based on this parameter. Figures 2-5 show system response versus the level of factors.

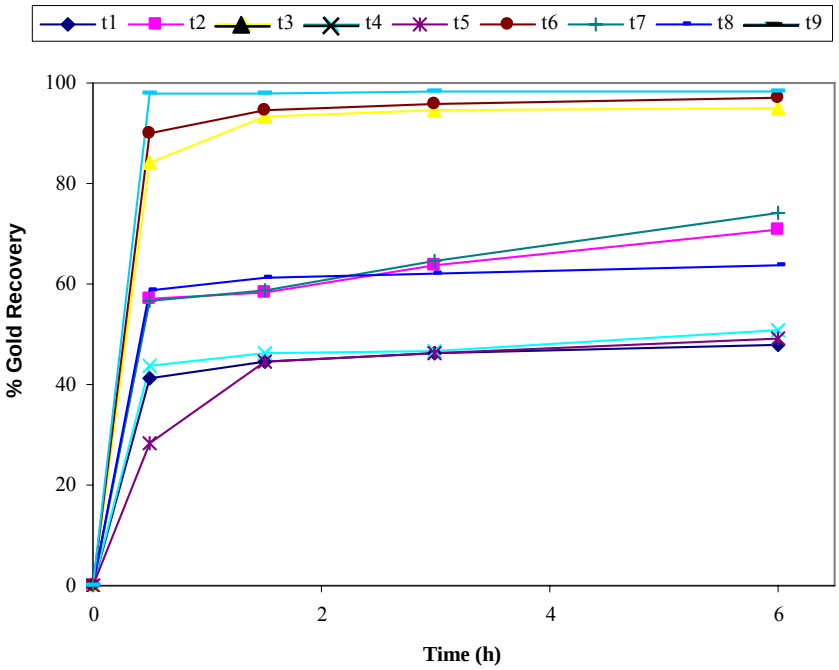

Figure 1. Gold Recovery with HSAS carbon

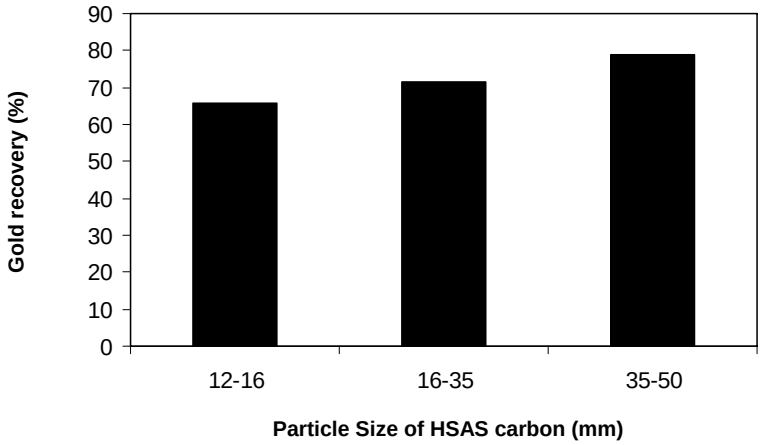

Figure 2. Average responses at different levels of particle size of HSAS carbon

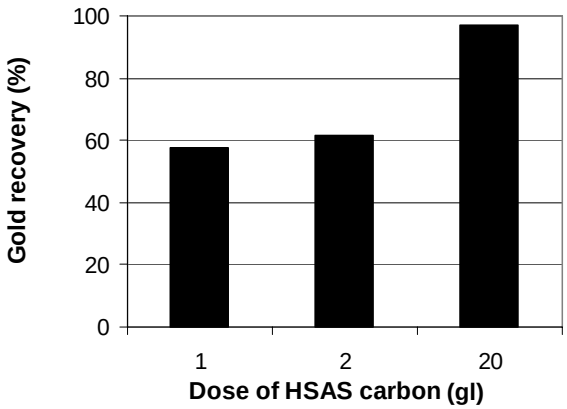

Figure 3. Average responses at different levels of dose of HSAS carbon

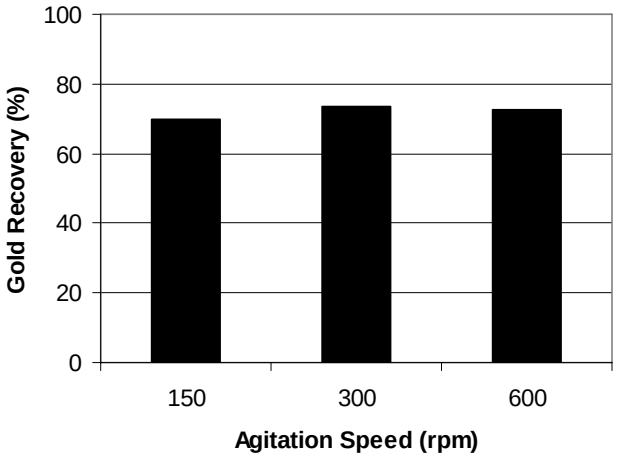

Figure 4. Average responses at different levels of agitation speed of mixing

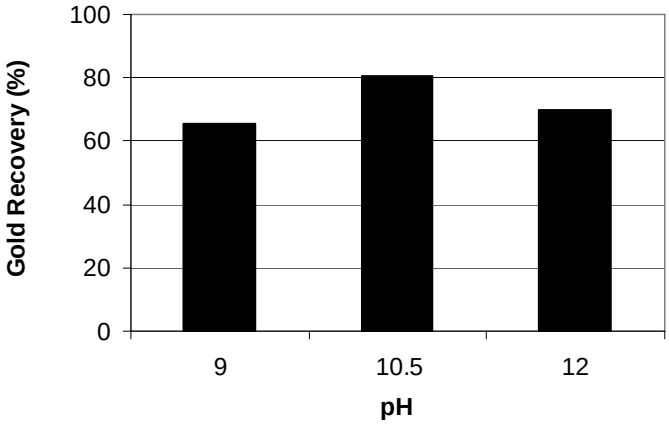

Figure 5. Average responses at different levels of pH

The data of these figures indicate, as it was expected, that the recovery of gold ions increases with the increase of the adsorbent dose and decrease the size of particles. In

these tests, range of agitation speed is from 150 to 600 rpm. As seen from Fig. 4, agitation speed level has little or no influence on the final gold recovery.

Based on these results, the optimum operating condition is achieved using HSAS carbon with 35-50 mesh and 20g/l concentration at pH =10.5 and average speed of mixing (300 rpm). Under the optimum operating conditions more than 98 per cent of gold is recovered by HSAS activated carbon.

Another step of the Taguchi method is the analysis of results or ANOVA table. The purpose of the ANOVA is to investigate which recovery parameters significantly affect the performance characteristic and the contribution of each parameter on the recovery efficiency. The percentage contribu-tion of each parameter in the total sum of the squared deviations can be used to evaluate the importance of the parameter change on the performance characteristic. In addition, the F- ratio can also be used to determine which parameters have a significant effect on the performance characteristic. The cal-culated values are then compared with F values predicted by statistical F distribution (in Fischer tables), at 95% and at 99% confidence levels. According to the rule, when the F calculated in the ANOVA table is bigger than the standard F, the parameter is significantly influenced by the response variable at the respective confidence level [40].

Results of ANOVA, which are shown in Table 4, indicate that the adsorbent dose is the most significant recovery process parameter due to its highest percentage contribution (81 per cent) among the process parameters as was expected, whereas agitation speed in the range studied has no considerable effect on the gold recovery, this parameter can be pooled and ANOVA table is changed to Table 5. According to Table 5, the maximum percent of error in the results is 2.97 percent, which is not important. From the Fisher tables with 90% and 99% confidence, $F_{0.1,\ 2,\ 2} = 9$, $F_{0.01,\ 2,\ 2}=99$ [40]. According to these values, it must be observed that the adsorbent size and pH variable influence the measurement errors at 95% confidence and the dose of adsorbent influences at 99% confidence.

Table 4. Results of the analysis of the variance (ANOVA table)

Process parameter	Sum of squares	Variance	F-ratio	Percentage of contribution
Adsorbent Size (mm) Adsorbent Dose (gl) Agitation Speed (rpm) pH Error	268.666 2832.666 25.996 370.666	134.333 1416.333 12.998 185.333		7.680 80.979 0.743 10.595
Total	3489.000			%100

Table 5. ANOVA Table after pooling the factor

Process parameter	Sum of squares	Variance	F-ratio	Percentage of contribution
Adsorbent Size (mm) Adsorbent Dose (gl) Agitation Speed (rpm) pH Error	268.666 2832.666 (25.996) 370.666 25.996	134.333 1416.333 ——— 185.333 13.000	10.334 108.960 Pooled 14.258	6.937 80.236 ——— 9.853 2.974
Total	3489.000			%100

An equation of order n to describe the gold recovery phenomena by activated carbons is proposed in the literature [16]:

$$\Delta\left[Au\right]_c^t = K\left[Au\right]_s^t t^m \qquad (6)$$

Where:

$\Delta\left[Au\right]_c^t$ = Increase concentration of gold on activated carbon (ppm) at time t

$\left[Au\right]_s^t$ = Gold Concentration in solution (ppm) at time t

t = time (hr)

K= rate constant (hr^{-1})

m= experimentally derived factor

Equation (6) can be written as follows:

$$\log\frac{\Delta\left[Au\right]_c^t}{\left[Au\right]_s^t} = m\log t + \log K \qquad (7)$$

By plotting the equation (7), the values of m and K can be determined from the slope and intercept at zero time. Rate equation parameters for these experiments are calculated and given in Table 6. It can be observed that the recovery rate depends on the particle size of the adsorbent and pH solution. This parameter is significantly reduced by increasing the particle size of the adsorbents and the pH solution.

Table 6. Kinetic Parameters for Gold Adsorption Experiments

Experiment No.	K (h^{-1})	m
t1	765.95	0.1054
t2	721.27	0.2321
t3	420.05	0.5197
t4	826.80	0.1035
t5	286.22	0.3550
t6	669.88	0.5164
t7	1454.12	0.3036
t8	757.01	0.0829
t9	2610.96	0.1381

3-3- Gold Adsorption Isotherms

The adsorption equilibrium studies were carried out at 25°C, 40°C and 60°C to determine the adsorption isotherms and the isotherm parameters were evaluated using non-linear Langmuir and Freundlich models [1]. The Langmuir equation may be written as:

$$q_e = \frac{Q^0 b\, C_e}{1 + b\, C_e} \qquad \text{(Non-linear form)} \qquad (8)$$

$$\frac{C_e}{q_e} = \left(\frac{1}{Q^0 b}\right) + \left(\frac{1}{Q^0}\right) C_e \text{ (Linear form)} \qquad (9)$$

where q_e is the amount of solute adsorbed per unit weight of adsorbent (mg/g), C_e is the equilibrium concentration of solute in the bulk solution (mg/l), Q^0 is the monolayer adsorption capacity (mg/g) and b is the constant related to the free energy of adsorption ($b \propto e^{-\Delta G/RT}$). It is the value reciprocal of the concentration at which half

the saturation of the adsorbent is attained. The Freundlich equation may be written as

$$q_e = K_F C_e^{1/n} \quad \text{(Non-linear form)} \qquad (10)$$

$$\log q_e = \log K_F + \frac{1}{n}\log C_e \qquad \text{(Linear form)} \qquad (11)$$

where K_F is the constant indicative of the relative adsorption capacity of the adsorbent (mg/g) and 1/n is the constant indicative of the intensity of the adsorption.

Figure 6 shows the equilibrium adsorption isotherms at various temperatures for gold ions with HSAS carbon. The adsorption isotherm can be mathematically adjusted by means of the equations 8-11. The corresponding Freundlich and Langmuir parameters, along with correlation coefficients, are given in Table 7. The correlation coefficients showed that, in general, the Freundlich model fitted the results better than the Langmuir model.

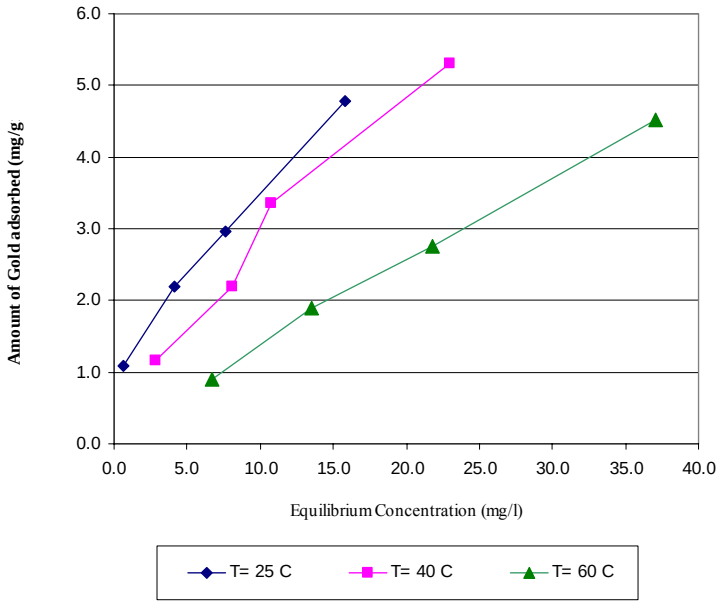

Figure 6. Equilibrium of gold adsorption with HSAS carbon at different temperatures

Table 7. Freundlich and Langmuir isotherm constants for the gold adsorption on HSAS

Temp.(°C)	Freundlich constants			Langmuir constants		
	K_F(mg/g)	1/n	R^2	Q^0(mg/g)	b	R^2
25	1.254	0.451	0.981	6.028	0.180	0.879
40	0.526	0.739	0.982	12.005	0.034	0.805
60	0.160	0.929	0.997	30.211	0.005	0.785

Thermodynamic parameters, namely, free energy (ΔG^0), enthalpy (ΔH^0)and entropy (ΔS^0) changes were also calculated using Eqs.(12)-(14) and are given in Table 8. The reference state was defined based on adsorption density in mg/g of adsorbent and concentration in mg/l:

$$\Delta G^0 = -RT \ln K_l \qquad (12)$$

$$\Delta H^0 = R\left(\frac{T_2 T_1}{T_2 - T}\right)\ln\frac{K_2}{K_1} \quad (13)$$

$$\Delta S^0 = \frac{\Delta H^0 - \Delta G^0}{T} \quad (14)$$

where K_1, K_2, and K_3 are the Langmuir constants the same as b_1, b_2, and b_3 corresponding to temperatures at 25°C, 40°C and 60°C. The negative value of ΔH^0 indicates that adsorption of gold onto activated carbon is an exothermic process, and an increase in temperature will shift the equilibrium to favor desorption.

Table 8. Thermodynamic parameters for the gold adsorption on HSAS

Temp.(°C)	ΔG^0(kJ/mol)	ΔH^0(kJ/mol)	ΔS^0(kJ/mol. K)
25	0.048	-85.714	-0.288
40	0.090		-0.274
60	0.134		-0.257

3-4- Comparison of gold recovery with different activated carbons

The recovery of gold with HSAS carbon at optimal operating conditions is compared to the commercial activated carbons. Table 9 gives the percent of gold recovery and kinetic parameters (K, m,).

It was found that the HSAS carbon has the same adsorption efficiency as other imported commercial activated carbons. It was seen that the K value of HSAS carbon is relatively higher than other carbons due to its higher surface area and volume of pores; therefore its recovery rate is faster than other imported activated carbon.

Table 9. Comparison of gold recovery with different activated carbons

Type of activated carbon	Gold recovery (%)	K(h^{-1})	m
HSAS	98.15	1778	0.2472
C2	97.69	1561	0.2068
C3	96.29	1436	0.1301
C4	97.92	1670	1.3346

4- Conclusion

As hard shells of apricot stones are discarded as waste from agricultural and food processing industries, the production of activated carbon from this waste is expected to be economical. In this study, conversion of hard shells of Iranian apricot stones to activated carbon for gold recovery from gold-plating wastewater was investigated. The required adsorbent was prepared by the chemical activation method with phosphoric acid. It was found that this carbon has a high iodine number, very low ash content and a large specific surface area that consists of a

large amount of micro pores.
The effect of several parameters such as the dose and particle size of the adsorbent, pH and agitation speed of mixing on the gold recovery was investigated. Experimental results showed that the maximum gold recovery was obtained during the 1.5 hours of contact time and recovery rate was relatively high at this time.
A Taguchi analysis of the data shows that the adsorbent dose is the significant recovery process parameter as was expected; however agitation speed on mixing in the range studied did not have a considerable effect on gold recovery. Moreover, the optimum operating condition was achieved using activated carbon with 35-50 mesh and 20g/l concentration at pH =10.5 and an average speed of mixing. This condition was similar to the industrial condition for the extraction of gold from cyanide pulp. Under the optimal operating conditions nearly 100 per cent of gold ions (98.15 per cent) were recovered by activated carbon after 3 hours.
Our studies suggest that activated carbon produced from the hard shell of Iranian apricot stones could be used as an effective adsorbent replacement for other imported commercial activated carbons due to its physical and chemical properties and adsorptive properties in gold recovery.

5. Nomenclature

C_0	initial gold ion concentration in solution (mg/l)
C_e	equilibrium initial gold ion concentration in solution (mg/l)
V	volume of solution (l)
W	adsorbent weight (g)
q_e	amount of gold adsorbed at equilibrium (mg/g)l
$\Delta[Au]_c^t$	Increase concentration of gold on activated carbon (g/t) at time t (hr)
$[Au]_s^t$	Concentration of gold in solution (ppm) at time t
K	rate constant (hr^{-1})
m	experimentally derived factor
t	time (hr)
Q^0	monolayer adsorption capacity (mg/g)
b	Langmuir isotherm constant
K_F	Relative adsorption capacity of the adsorbent (mg/g)
1/n	Freundlich isotherm constant
ΔG^0	free energy changes (kJ/mol)
ΔH^0	enthalpy changes (kJ/mol)
ΔS^0	entropy changes (kJ/ mol K)
T	Temperature (K)
R	Gas constant(??????????????)

6- Acknowledgement

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